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Comparison of Digital Elevation Model from Consumer Grade Drone for Shallow-Water Bathymetry at Redang Island Marine Park, Terengganu.

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Abstract

The most common and best method of obtaining shallow-water bathymetry is using a single-beam echosounder (SBES). There were numerous studies on drone DEM for shallow river basins and coastal areas, but not on shallow-water coral reef areas. Thus, this study was carried out to compare the DEM produced by a consumer-grade drone with the bathymetry obtained from SBES for a shallow-water reef area in Redang Island Marine Park. The DJI Phantom 4 with 1/2.3” CMOS camera sensor was used to capture images using automated DroneDeploy application. Besides, the bathymetry survey was conducted using SBES Hummingbird 581iHD Down Imaging™. The data were processed using DroneDeploy Proprietary Map Engine (Drone) and Hypack Max 2014 (SBES), which then were extracted and compared. The results indicated the shallowest level at the sandy beach (0m to -1m) had the lowest RMS error (RMSE: 0.230m, R^2: 0.499), in comparison with other depth classes at both sandy beach and rocky shore. Therefore, the bathymetry derived from a consumer-grade drone DEM, based on an RGB sensor is not suitable to be used for safety navigation mapping, but it can be applied for other coastal management purposes, such as shoreline mapping and monitoring.

Keywords: Drone, Bathymetry, Shallow Water Reef, Digital Elevation Model (DEM), Single Beam Echosounder (SBES)

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Abstrak

Kaedah yang paling biasa dan terbaik untuk mendapatkan batimetri air cetek adalah menggunakan echosounder rasuk tunggal (SBES). Terdapat banyak kajian mengenai drone DEM untuk lembangan sungai cetek dan kawasan pantai, tetapi tidak di kawasan terumbu karang air cetek. Oleh itu, kajian ini dijalankan untuk membandingkan DEM yang dihasilkan oleh dron gred pengguna dengan batimetri yang diperoleh daripada SBES untuk kawasan terumbu air cetek di Taman Laut Pulau Redang. DJI Phantom 4 dengan sensor kamera

CMOS 1/2.3” digunakan untuk menangkap imej menggunakan aplikasi DroneDeploy automatik. Selain itu, tinjauan batimetri telah dijalankan menggunakan SBES Hummingbird 581iHD Down ImagingTM. Data telah diproses menggunakan Enjin Peta Proprietari DroneDeploy (Drone) dan Hypack Max 2014 (SBES), dan kemudian telah diekstrak dan dibandingkan. Keputusan menunjukkan aras paling cetek di pantai berpasir (0m hingga -1m) mempunyai ralat RMS terendah (RMSE: 0.230m, R2: 0.499), berbanding dengan kelas kedalaman lain di kedua-dua pantai berpasir dan pantai berbatu. Oleh itu, batimetri yang diperoleh daripada DEM dron gred pengguna, berdasarkan penderia RGB tidak sesuai digunakan untuk pemetaan navigasi keselamatan, tetapi boleh digunakan untuk tujuan pemetaan dan pemantauan garis pantai.
Kata Kunci: Dron, Batimetri, Terumbu Air Cetek, Model Ketinggian Digital (DEM), Echosounder Rasuk Tunggal (SBES)

Introduction

Bathymetry is part of the main component for hydrographic study, where it assesses the depth of water bodies, like ocean and river, making it one of the important fields in the marine study. There are many methods for conducting bathymetry, but the most common method for shallow water areas is using Single Beam Echosounder (SBES). The SBES has been used widely to monitor and assess the morphology of water bodies, such as a river as it is convenient to be used in shallow water areas (Flener et al, 2015; Kasvi et al, 2017; Arseni et al, 2019). However, the SBES is not practically suitable for bathymetry if the study area is huge. Besides, the cost to operate the SBES was high as this method require a boat, but it is also time-consuming as it need to move at a slower speed, to prevent misreading of water depth.

To overcome the limitation, people started to use remote sensing as alternatives, and Light Detection and Ranging (Lidar) is one of it. Lidar have been used among researchers to conduct bathymetry surveys for huge areas and with high-resolution data, compared to satellite imagery (Tonina et al, 2018). Not only does it require less time to conduct, but it also provides an accurate surveying method for shallow water areas (Guenther, 2007). Even though this alternative has solved the issue of a wide area, the cost for Lidar bathymetry is high, and not many researchers are capable to use it continuously (Kasvi et al, 2019).

Therefore, the emergence of consumer-grade drone, or known as Unmanned Aerial Vehicle (UAV) recently has provide opportunity for a low-cost aerial survey. The Red-Green-Blue (RGB) spectral sensor on every consumer-grade drone has provide affordable data source (Nezami et al, 2020) and capable to fly at high altitude and record high resolution of images, which cover huge area.

In recent years, some researchers have studied the efficiency of drone DEM compared with the conventional method. For example, Kasvi et al (2019) have conducted a comparison study on the bathymetric river model between drone Structure from Motion (SfM) or DEM with Acoustic Doppler Current Profiler (ADCP) DEM. Similarly, a study by Dietrich (2017) also tested the bathymetric SfM on shallow streams. Both studies have been conducted on shallow river basins, and none has been tested for shallow water in a coastal area. Therefore, this study was initiated to compare the bathymetry DEM produced using consumer-grade drone and SBES for shallow-water reef areas in Redang Island Marine Park, Terengganu, Malaysia.

Materials and Methods

Research Area

The study was conducted at the North-Eastern of Redang Island Marine Park (Figure 1), which is located about

45km away from the Kuala Terengganu coastline, The research area, as marked with a grey rectangle in Figure 1 was selected due to availability and accessibility of the shallow-water reef area in the island. The depth of the sampling area was shallow, which was less than 10m depth, making it suitable for the testing and the area consists of wide coverage of shallow-water coral reefs the water turbidity was low and clear of sedimentation, which was an advantage for aerial surveys using a consumer-grade drone.

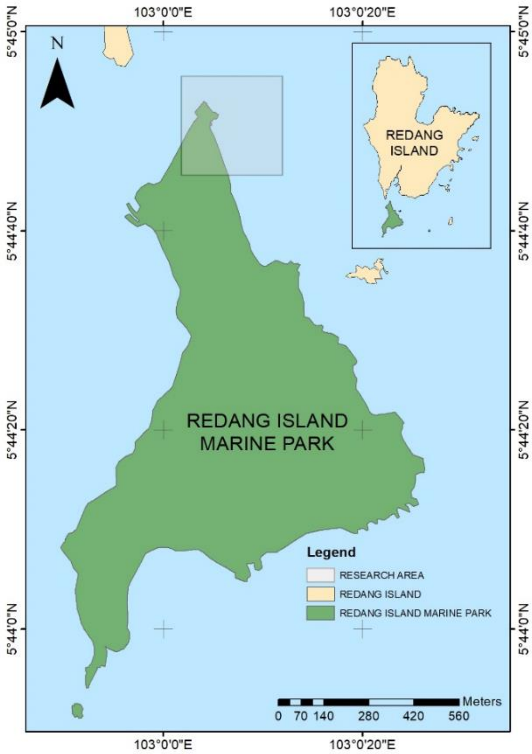

Figure 1 Location of research area (Grey Rectangle) in Redang Island Marine Park (Left) and Aerial View of the research area (Right)

Drone & Bathymetry Survey

Before performing the drone survey, 10 Ground Control Points (GCP) were placed randomly along the research area and their coordinates were recorded using a handheld Garmin GPSMAP device (Figure 2). The locations of GCPs, to provide better accuracy for data georeferencing later (Aarnink, 2017). The GCPs were georeferenced using ArcMap software after the drone images were processed into orthomosaic.

Figure 2 Example of GCP placed at different locality; beach (Left) and at shallow water areas (Right)

The consumer-grade drone DJI Phantom 4 with an onboard 1/2.3" CMOS camera sensor was used in this study, that capable to capture RGB spectral (Onishi & Ise, 2018). flight plans were set up using DroneDeploy application so that flight was controlled automatically and captured the required data every 2 seconds (Reali, 2018). The acquired data from the drone must be overlap more than 90%, to produce a good orthomosaic of the research area (Casella, 2017) The drone was set up to fly at 30m height, covered a total area of $0.11km^2$ (Figure 3). The flight time was standardized between 4 pm to 6 pm and during low tide, to avoid excessive sun and glint disturbance on the water.

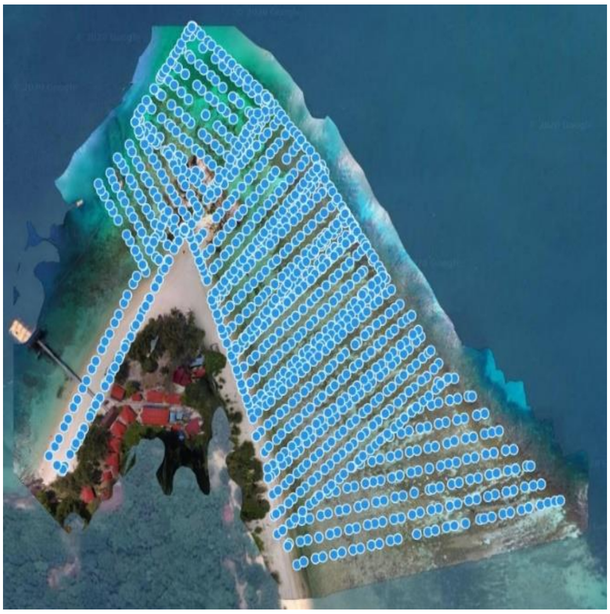

Figure 3 Overall 8 Automated Flight Plan of DroneDeploy on Research Area

As for bathymetry, the survey was conducted using SBES, modelled Hummingbird 581iHD Down Imaging™. This SBES model recorded depth up to 76m at the frequency of 800kHz. The SBES echosounder was mounted on side of the boat and connected to the tough book, where the data was recorded using Hypack Max 2014. The boat moved along the transect lines with 20-meter gap between transect at constant speed (Figure 4).

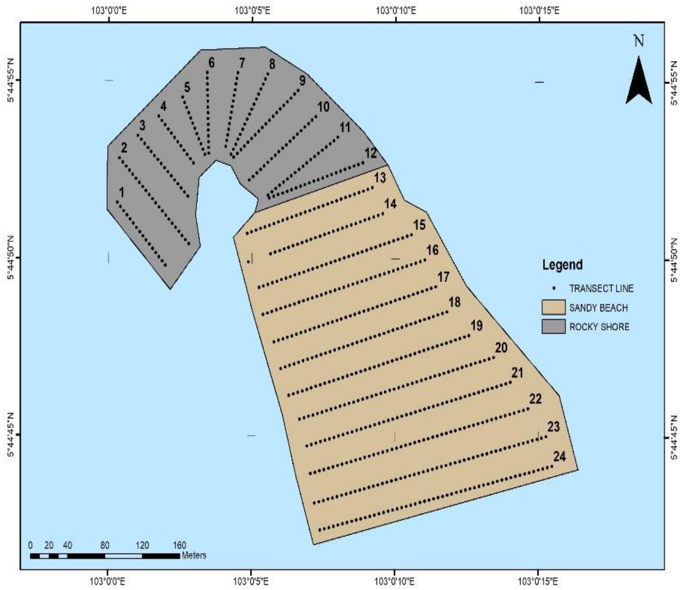

Figure 4 The Transect Lines for Bathymetry Survey, with twelve transect lines located at Rocky Shore and twelve transect lines at Sandy Beach.

Data Processing and Analysis

The data captured from drone and bathymetry surveys were processed using DroneDeploy Proprietary Map Engine and ArcGIS software, respectively. The DroneDeploy software combined all aerial images with elevation data from all flight plans, producing orthomosaic aerial images, along with DEM data. While the data recorded from bathymetry is extracted and processed using ArcGIS Kriging interpolation to produce bathymetry DEM with masking isolating for water area only. Kriging interpolation has shown better performance and is considered as best interpolation method for the bathymetric DEM model, as it is much efficient compared to Inverse Distance Weighted (IDW) (Ferreira et al, 2017; Parente and Vallario, 2019). Then, by using similar transect lines as in the bathymetry survey (Figure 4), the elevation values are extracted from both drone and bathymetry DEM. The DEM value was extracted into 24 transects, 12 at rocky shore and the other 12 at sandy beach regions, following the transect lines in Figure 4 The extracted values from both DEMs were then segregated into 2 regions, rocky shore, and sandy beach, at 4 different depth classes of -1m, -4m, -7m, and -9m. Finally, the data was compared statistically using R^2, RMS Error, and confidence band.

Results & Discussion

From the research survey, the drone data have produced orthomosaic and DEM maps (Figure 5). The Orthomosaic shows the top view of the survey area, which covered large coral reef area, rocky shore and a shipwreck at northern part. While the DEM shows the depth gradient, from shallow to depth (light brown – dark brown). The data have been georeferenced with all the GCPs, resulting in low RMS error (0.27m). While Figure 6 shows the map of comparison between the DEM of drone and bathymetry. The distinct difference between the DEM of drones and SBES can be seen in the north part of the research area. The north area is categorized as a rocky shore, while the middle until to south is categorized as a sandy beach, as referred to in Figure 4.

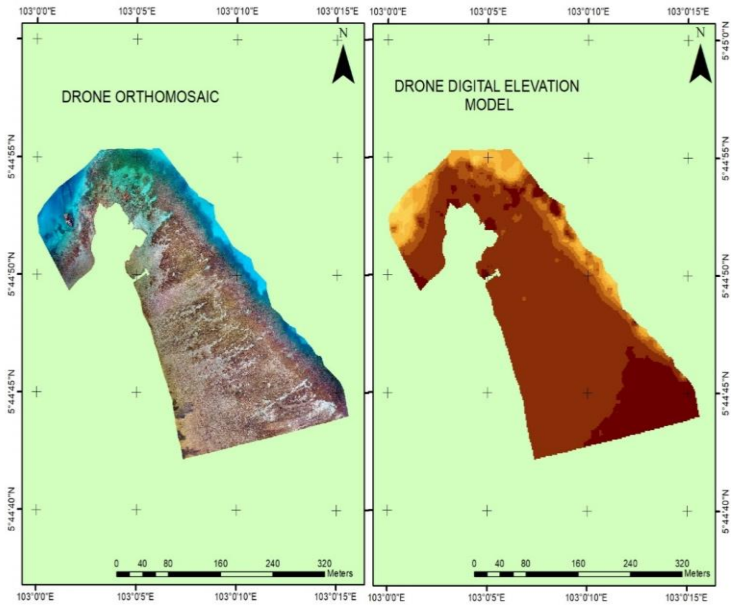

Figure 5 The Drone Orthomosaic (Left) and DEM (Right) of Research Area

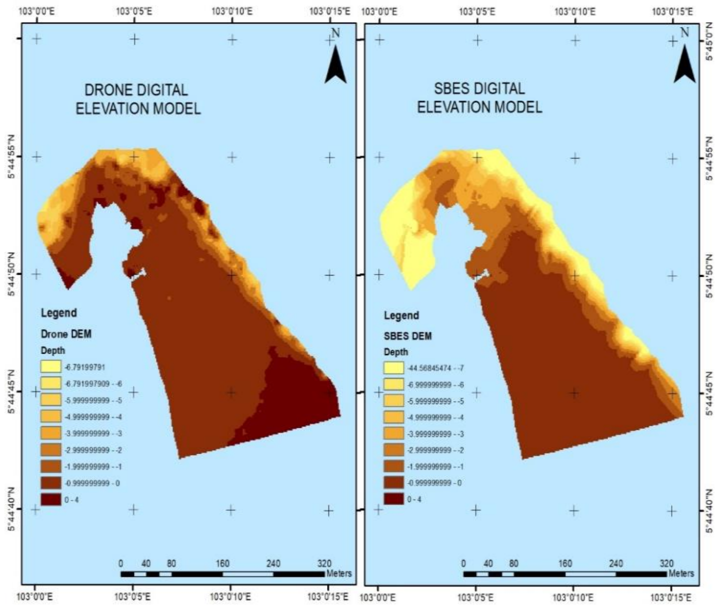

Figure 6 The DEM Comparison Between Drone (Left) and Bathymetry (Right)

As the data of drone and SBES were extracted by transects, the results were visualized into depth profiles of rocky shore (Figure 7) and sandy beach (Figure 8). From the profile comparison, the biggest difference between drones and SBES can be referred at the rocky shore, with a huge gap of more than 5m between drone and SBES depth data. This is due to the inaccessibility of the boat in the area, to conduct the SBES survey. Thus, the data interpolation only takes account the outer data that much deeper than the actual depth, making the SBES DEM data of the area not accurate. This shows the limitation of SBES compared to drones, which can reach difficult areas.

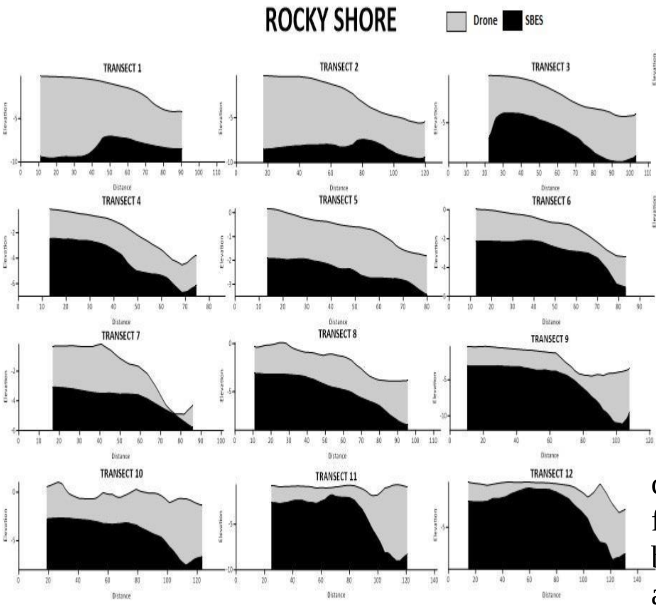

Figure 7 The Profile Comparison between Drone (Gray) and SBES (Black) at Rocky Shore

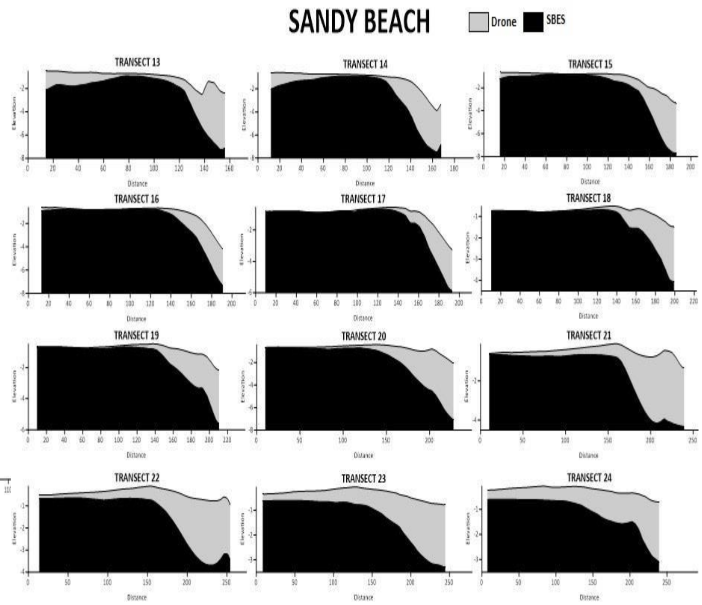

Figure 8 The Profile Comparison between Drone (Gray) and SBES (Black) at Sandy Beach

As for the statistical data, the result can be referred to Table 1, where the data from both DEM of drone and SBES have been compared by Confidence Band, R^2, and RMS Error. The sandy beach has an overall R^2 value higher compared to the rocky shore, which is all below 0.1 RMS error for rocky shore was higher compared to the sandy beach, indicated the data at the rocky shore unreliable and not accurate. The issue can be referred to as the inaccessibility of the SBES survey at rocky shore area, due to difficult morphology. Focusing on the sandy beach, the highest R^2 recorded among the depth is at -7m to -10m (0.641), followed by -1m to -4m (0.573), 0m to -1m (0.499), and -4m to -7m (0.388). Even though the R^2 at -7m to -10m is the highest, the RMS error is also the highest (4.962m), compared to other depth, followed with -4m to -7m (3.520m), -1m to -4m (1.301m), and the lowest RMS error is 0m to -1m (0.230m). Comparing the four depths level at the sandy beach, the shallowest level (0m to -1m) drone data have shown its reliability when tested with SBES data, as it is the only one level that has RMS error less than 0.5m. The high in R^2 indicates similarities between the drone and SBES data, while lower R^2 may represents gaps between the depth in drone and SBES data.

The mean of SBES and drone data at the shallowest level have the closest value, which is at -0.71 and -0.54, respectively. The shallowest level a standard deviation at the level has also had the lowest value, compared to other depth levels. From all these data analyses, it has been shown that the reliable drone data is at the depth level of 0m to -1m, which has the lowest RMS error 0.230m., this finding was compatible with the study done by Kasvi et al (2019), where the drone bathymetry SfM data recorded during Autumn and Spring were low (0.56 and 0.01) compared to the validation points. Kasvi et al (2019) also performed post-processing in eliminating all negative modelled depth and acquired low RMS error (R^2 of 0.51 and 0.73), at depth <0.8m.

Table 1. Statistical Analysis

Categories	Class, m	SBES		Drone		Confidence Bands					R^2	RMSE
		Mean	Standard Deviation	Mean	Standard Deviation	Slope, m	Intercept	Standard Deviation in Estimation	SSX	t		
Sandy Beach	0 to -1	-0.71	0.10	-0.54	0.21	1.519	0.535	0.154	0.005	1.968	0.499	0.230
	-1 to -4	-1.98	0.90	-0.86	0.34	0.558	1.000	0.787	1.425	2.079	0.573	1.301
	-4 to -7	-5.26	1.01	-1.89	0.99	0.291	-0.291	0.228	0.378	1.997	0.388	3.520
	-7 to -10	-7.93	0.51	-3.06	1.36	2.123	13.780	0.845	1.453	2.144	0.641	4.962
Rocky Shore	-1 to -4	-2.83	0.64	-0.75	0.55	0.261	-0.011	0.532	4.885	1.992	0.091	2.196
	-4 to -7	-5.52	0.81	-2.52	1.56	0.380	-0.427	1.552	8.591	2.034	0.039	3.389
	-7 to -10	-8.96	0.93	-2.49	2.17	0.059	-1.962	2.173	0.657	2.008	0.003	6.856

As been mentioned, due to inaccessible boat to the rocky shore area, the data collection for the area become difficult and the data become scarce. With limited perception of drone data at deeper area, the production of DEM at the rocky shore area becomes much deeper compared to other areas, thus not representing the real data at rocky shore. Thus, the comparison between the drone and bathymetry at the rocky shore area was not reliable. The problem can be solved using a smaller carrier, like a Remotely Operated Vehicle (ROV) mounted with SBES. Previously, Di Risio et al (2018) have tested the usage of ROV to perform bathymetry, with sonar. With bathymetry data from ROV, the comparison of the bathymetry accuracy between drones and SBES can be done.

For the sandy beach region, the drone DEM at depth of -1m showed high accuracy with the lowest RMS error compared to other depths. This indicated the reliability of the data, similarly to the study done by Kasvi et al (2019). There was one factor that may affecting the accuracy of the drone data, which was due to many flight plans performed, instead of one flight plan to cover the whole area. In this study, 8 flight plans were performed to cover the whole study area, due to the drone's battery capacity that only allowed a max of 20 minutes of flight time. With several flights performed to cover the whole study area, the data from each flight may showed significant differences and affected the data accuracy. The issue can be resolved with the usage of a better and higher battery capacity drone, which can record the whole study area

Due to the low accuracy at depth more than -1m, the drone bathymetry was not appropriate to be used for deep bathymetry survey and navigational purposes, however it is an excellent option for shoreline mapping and monitoring. the usage of a consumer-grade drone to monitor the changes on shoreline and shallow-water areas, up to a depth of -1m can be conducted frequently and easily, compared to the conventional method. The consumer-grade drone also has shown its capability in accessing difficult areas, such as rocky shore, better than the conventional bathymetry method, the SBES.

Conclusions

The consumer-grade drone has shown its capabilities in accessing shallow water bathymetry making it a much better instrument to be. In terms of the accuracy of bathymetry, the drone is suggested to be used for the area that has a depth not more than -1m with clear water conditions. The accuracy and precision of drone bathymetry can be improved in the future by using a multispectral sensor with Real-Time Kinematic (RTK) GPS and a much high-end model of drone.

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Authors' Contributions

ZA, MIHMJ, AHA, MAZ and MZM conceived the ideas and designed the methodology; ZA, MIHMJ, AHA, MAZ, MZM, AYA, JOLS, ZK, AAC, and MKR helping in collected the data; MIHMJ and AHA analysed and interpreted the data; ZA and MIHMJ led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Competing Interests

The authors declare no competing interest.

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